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TRANSFER ORBIT STAGE  
MECHANISMS THERMAL VACUUM TEST  
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ABSTRACT:

Martin Marietta recently conducted a systems level mechanisms test on the Orbital Sciences Corporation's (OSC) Transfer Orbit Stage (TOS). The TOS is a unique partially reusable transfer vehicle which will boost a satellite into its operational orbit from the Space Shuttle's cargo bay. The mechanical cradle and tilt assemblies will return to earth with the Space Shuttle while the Solid Rocket Motor (SRM) and avionics packages are expended.

A mechanisms test was performed on the forward cradle and aft tilting assemblies of the TOS under thermal vacuum conditions. Actuating these assemblies under a 1 g environment and thermal vacuum conditions proved to be a complex task. Pneumatic test fixturing was used to lift the forward cradle, and tilt the solid rocket motor (SRM) and avionics package. Clinometers, linear voltage displacement transducers (LVDT), and load cells were used in the thermal vacuum chamber to measure the performance and characteristics of the TOS mechanism assembly.

Incorporation of the instrumentation and pneumatic system into the test setup was not routine since pneumatic actuation of flight hardware had not been previously performed in our facility. This paper presents the methods used and the problems experienced during the design, setup and test phases of the TOS mechanisms thermal vacuum test.

INTRODUCTION:

The TOS system uses mechanical actuators to open a forward cradle and tilt the aft assembly which holds a satellite and TOS SRM and avionics package (figure #1). Tests were conducted on the TOS system at ambient temperature and pressure conditions, and worst case cold at vacuum. The TOS Mechanisms test had five primary objectives:

- 1.) Measure the rotational resistance of the forward cradle hinge and the aft cradle trunnions due to:
  - a. manufacturing tolerances
  - b. worst case cold temperatures (-65°F)
  - c. locked aft trunnion pins
  - d. stiffness of ASE/orbiter wire harness
- 2.) Demonstration of complete latch operation of the forward cardle including the proper operation of system indicators. This also encompassed testing for the latch grab envelope for the system which demonstrated stow capabilities during a possible abort situation.
- 3.) Demonstrate overall system functionality, including MLI and structural interferences during system operation.
- 4.) Verification of system indicators and microswitch operation i.e., aft cradle tilt up, aft cradle full down, and forward cradle down indicators.

- 5.) Comparison of operation between ambient and worst case cold temperature conditions.

To accomplish these objectives a unique test setup was needed with a number of complex fixtures and special instrumentation.

#### TEST FIXTURING:

The test fixturing included:

- 1.) Two Pneumatic actuators in heated enclosures, mounted on an overhead structure and attached to the chamber lid hardpoints.
- 2.) Valve bank control assembly for the operation of the pneumatic actuators.
- 3.) Test support structure in which the vehicle was mounted horizontally (x-axis) by its forward and aft trunnions. This structure mounted to the chamber floor hardpoints, with allowances for thermal expansion and contraction.
- 4.) Heated enclosures for test instrumentation and test tools, such as the thrust vector control test tool (TVC), pneumatic actuators, trunnions, load cells, LVDTs, and clinometers.
- 5.) Aft trunnion locking fixtures were built to hold the aft trunnion bearings in place so the secondary rotation of the aft assembly could be proven and the resistance measured. These were secured to the trunnions and mounted to the vehicle support structure.
- 6.) A SRM Simulator was constructed. The actual SRM was too heavy to be used for this test.

#### PNEUMATIC CONTROL SYSTEM

The rotation (lifting) of the flight hardware was accomplished with pneumatic actuators which pulled cables that lifted the forward cradle and tilted the aft assembly.

The pneumatic actuators were operated manually by adjusting hand valves which were located on a system valve bank assembly (figure #2). This proved to be a simple and effective method of operating the actuators.

The pneumatic actuators were special ordered with Buna-N seals for vacuum compatibility. Functional tests were performed on the actuators to ensure their integrity.

A full system verification was performed with the actuators on the support assembly. During checkout, a frictional binding problem in the actuators was discovered. To reduce the side loading on the piston, a swiveled pulley was attached to the end of the actuator piston, allowing it to rotate freely (figure #3). The bolts which mounted the pneumatic actuator to the support structure were loosened 1/4", to allow the actuator to float, thus reducing the torsion acting on the actuator. The tilt actuator was hung vertically and pinned at one end which allowed it to move freely (figure #4). This setup reduced the friction sufficiently to allow the hardware to be moved in a smooth manner.

The system was proofloaded to two times the expected operating loads. The pneumatic system applied the appropriate loads to pull the cable to mechanically proofload the pneumatic test fixture. Both actuators were pulled simultaneously. Load cells were used to verify the proper loads.

#### TEST INSTRUMENTATION:

Two hundred and thirty thermocouples were used to control kill and monitor temperatures on the unit, fixtures and chamber.

Four video cameras were used to monitor the actuation of the flight hardware. Three were installed in the chamber and enclosed in cases where they were maintained at ambient temperature and pressure. The first camera viewed the forward cradle latch microswitch to verify complete latch operation. The second was located at the aft cradle full up tilt microswitch to monitor its activation, the third viewed the hinge actuator during its deployment. The fourth camera was mounted to a viewport on the chamber lid, outside the chamber. It was used to view the entire operation. The valve bank operator used this monitor to control the lift and tilt operations.

Two load cells were used to obtain force vs angle data for post frictional analysis. To obtain the accuracy required for the frictional analysis, a special calibration was performed on the load cells. This special calibration gave a load cell accuracy of +/- 2 lbs. One load cell was installed in line on the cable which lifted the forward cradle. The second was installed in line, on the cable which tilted the aft assembly.

Four clinometers were used to obtain force vs angle data, and rates of rotation in degrees/minute. Two were attached to the forward cradle and two to the aft assembly.

Two linear voltage displacement transducers (LVDT) were used to measure the initial unlatch displacement of the top side of the forward cradle with respect to the lower section of the forward cradle, and to verify the cradle returned to its original position after rotation. They were also used to place the upper forward cradle in the outer limits of the latch grab envelope, so the envelope could be verified. These were attached to the latch side of the forward cradle on the lower section. These too were heated and thermally isolated from the vehicle such that they could be maintained at their ambient calibration temperature.

All load cells, clinometers, and LVDT's were maintained at ambient temperature to ensure calibration integrity.

Redundancy was used for all critical test instrumentation except the load cells, physical restraints prevented their redundancy. A bound spring on one LVDT limited the plungers range. One of the aft assembly clinometers failed.

## VEHICLE SETUP:

The TOS was mounted horizontally in its support structure in the thermal vacuum chamber (figure #5). The forward cradle flight hinge actuators and the aft cradle flight tilt actuators, two each, were disconnected so they could be operated without exceeding their zero g design limitations. The shuttle interface harness was configured in a flight like manner to simulate harness stiffness during rotation. Pneumatic actuator lifting interfaces were installed on the vehicle and the lift cables and instrumentation connected. MLI was not installed on the top section of the forward cradle for two reasons, first to help induce temperature gradients between the forward and aft sections of the forward cradle, secondly, eliminate MLI interference with the lift fixture.

## MECHANISMS TESTS:

### Deployment:

The test consisted of opening the forward cradle  $60^\circ$ . The full open position for the cradle is  $102^\circ$ , but due to chamber size limitations,  $60^\circ$  was the maximum it could be rotated. The full open microswitch activation for the forward cradle was verified through floor tests, using an overhead crane.

The aft assembly was tilted  $42^\circ$  to activate the deployment microswitch. When the activation of the microswitch was verified, the aft assembly was rotated to  $45^\circ$  to verify full tilt capability. This is done because the primary and secondary tilt actuators are offset, with the primary actuator capable of tilting  $42^\circ$ , the secondary  $45^\circ$ .

### Stowing: Latch Grab Test

Stowing is accomplished by lowering the forward cradle onto the aft cradle, then latching the forward cradle, thus securing both the forward and aft sections. This test was conducted to ensure the forward cradle and aft assemblies would stow and latch properly under worst case conditions. The latching mechanism was designed with a two inch latching envelope. Since the latch actuators could exert enough force to damage the test actuators, precautions were taken during this test to prevent this occurrence.

The forward cradle was lowered within two inches of its stowed position. At this distance the latches were required to open to their maximum range to grab the cradle and pull it into a locked position. During latching operations, the test actuators supported the forward and aft assemblies.

The full up deployment, and stowing routines were repeated three times at ambient temperature and pressure and three times at worst case cold under vacuum conditions. The data received from these tests was used to extract forces due to gravity and rotation resistance.

THERMAL VACUUM TEST RESULTS:

The predicted loads for a given angle vs the approximate actual loads for the operation of the forward cradle are shown below:

	<u>Degrees Rotation</u>	<u>Predicted Loads</u>	<u>Actual Loads</u>	<u>Maximum Allowable Load</u>
Ambient	0°	1196 lbs	1220 lbs	1450 lbs
Cold (-65°F)	0°	"	"	"
Ambient	60°	960 lbs	480 lbs	"
Cold (-65°F)	60°	"	"	"

The predicted loads for a given angle vs the approximate actual loads for the operation of the aft cradle are shown below:

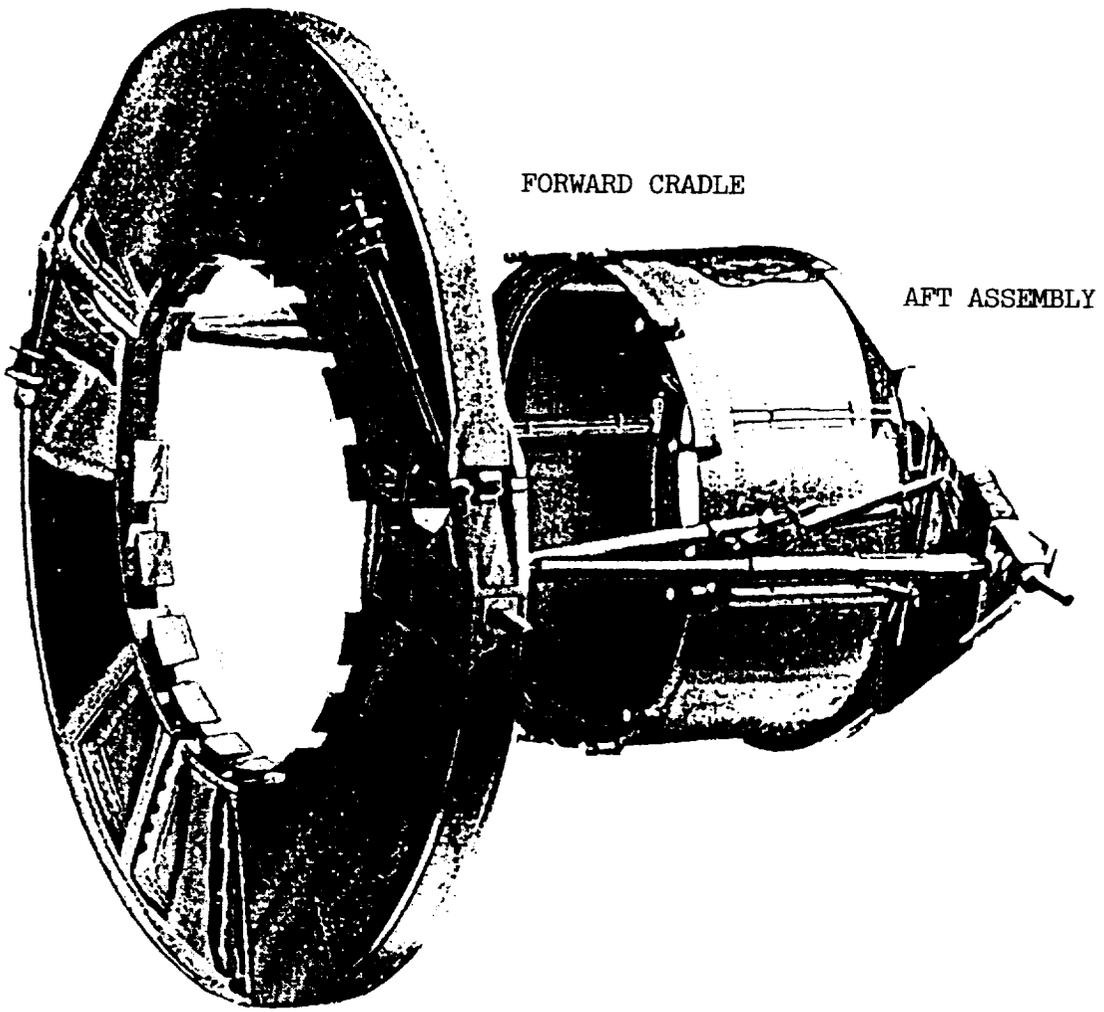
	<u>Degrees Rotation</u>	<u>Predicted Loads</u>	<u>Actual Loads</u>	<u>Maximum Allowable Load</u>
Ambient	0°	1678 lbs	1740 lbs	1750 lbs
Cold (-65°F)	0°	"	*1927 lbs (max)	"
Ambient	45°	1307 lbs	1376 lbs	"
Cold (-65°F)	45°	"	"	"

During lift and tilt operations, rates of 38.25 deg/min on the forward cradle and 15.75 degrees/min of the aft cradle were desired. Due to the time required to accelerate and decelerate, these rates were achieved only for a short period of time.

\*During the first tilting operation of the aft cradle, the aft cradle would not move at the allowable loading of 1750 lbs. A decision was made to exceed the allowable load by a maximum of 200 lbs to see if the aft cradle would free itself from the lower section of the forward cradle. The aft cradle came free at 1927 lbs, loads through the remainder of the rotation returned to normal. The binding of the aft cradle was caused by preloading in the forward cradle pads, and the contraction of the forward cradle at cold conditions. The second actuation also exceeded the maximum load at 1815 lbs. The last actuation was within tolerance at 1725 lbs.

SUMMARY:

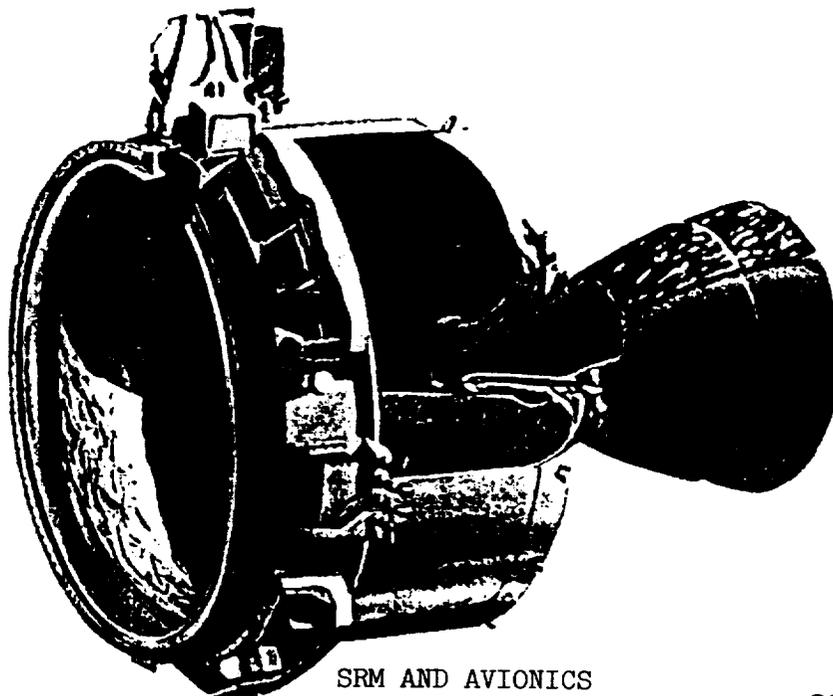
The mechanisms test successfully met its objectives by verifying the TOS's operational envelope, and qualifying the vehicle's mechanisms in a worst case cold environment. They revealed a problem in the design and preloading of the forward cradle pads. The two 10° pads were redesigned to prevent them from binding. The frictional analysis showed no major differences between the ambient temperature and cold temperature friction for the forward cradle and only a slightly higher loading for the tilting operation. These loads were acceptable and within the design range of the flight actuators.



FORWARD CRADLE

AFT ASSEMBLY

MECHANISM ASSEMBLY



SRM AND AVIONICS

Figure 1.

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# LIFT AND TILT ASSEMBLY PLUMBING AND VALVING

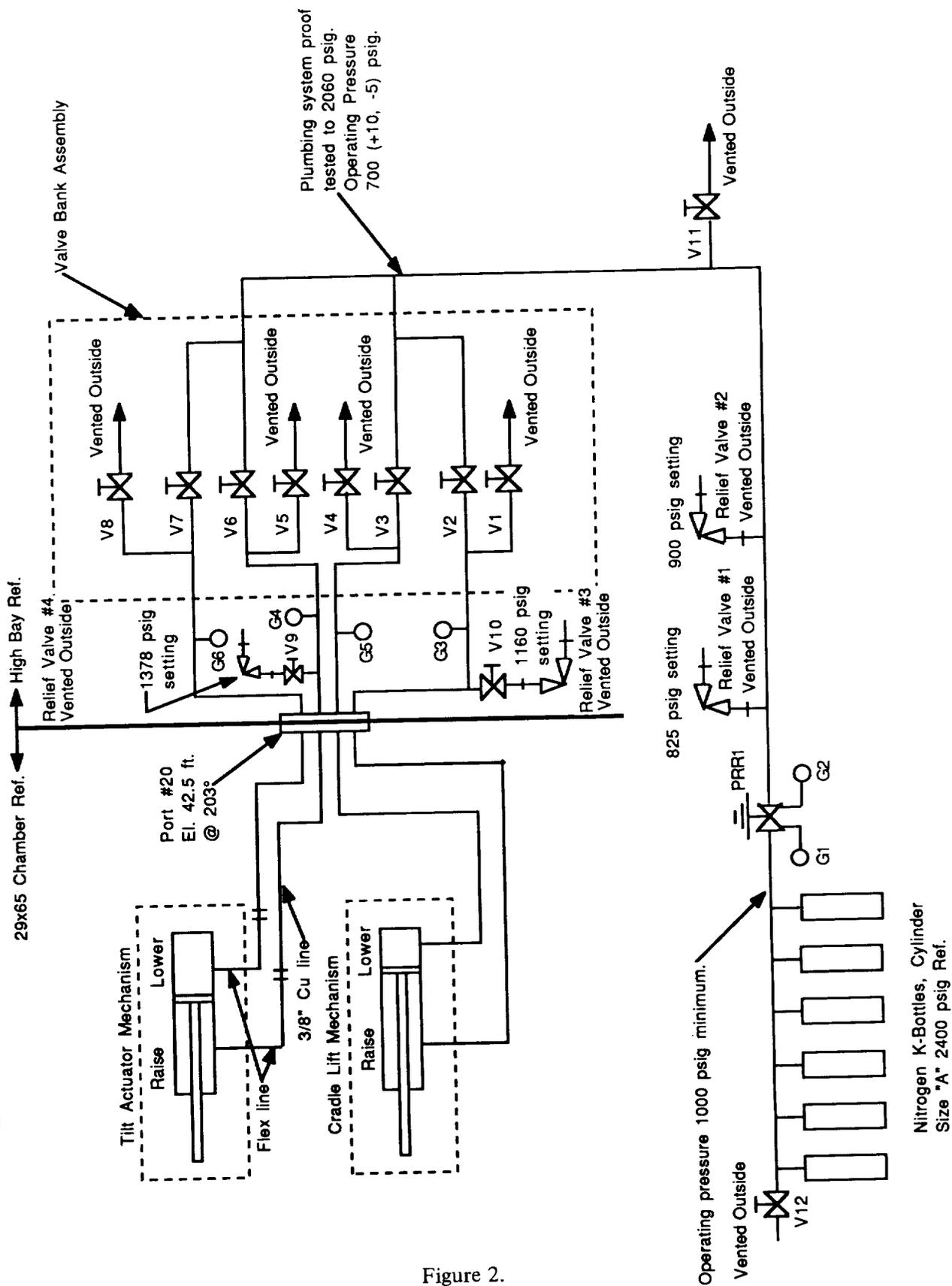


Figure 2.

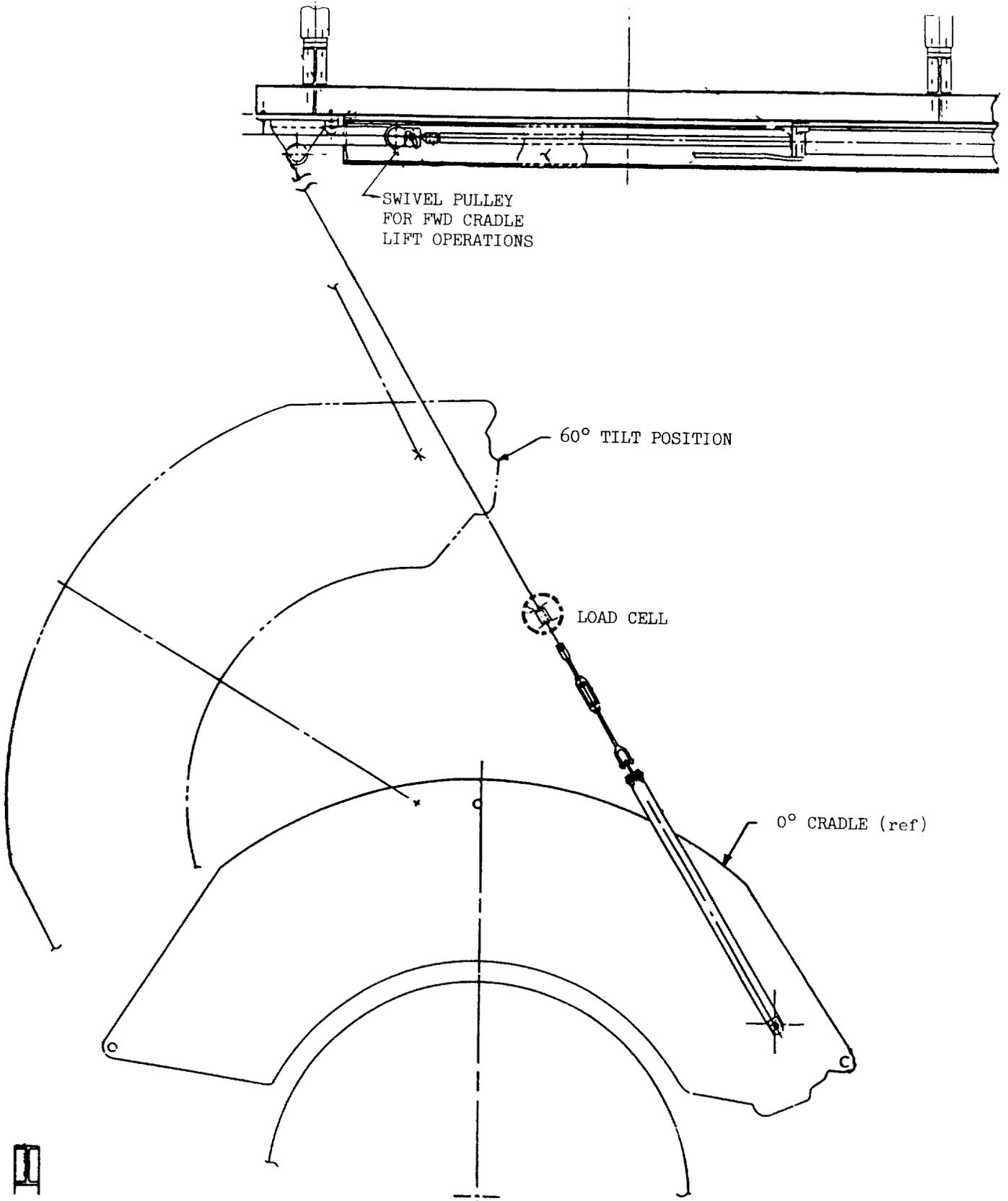


Figure 3. Forward Cradle Lift

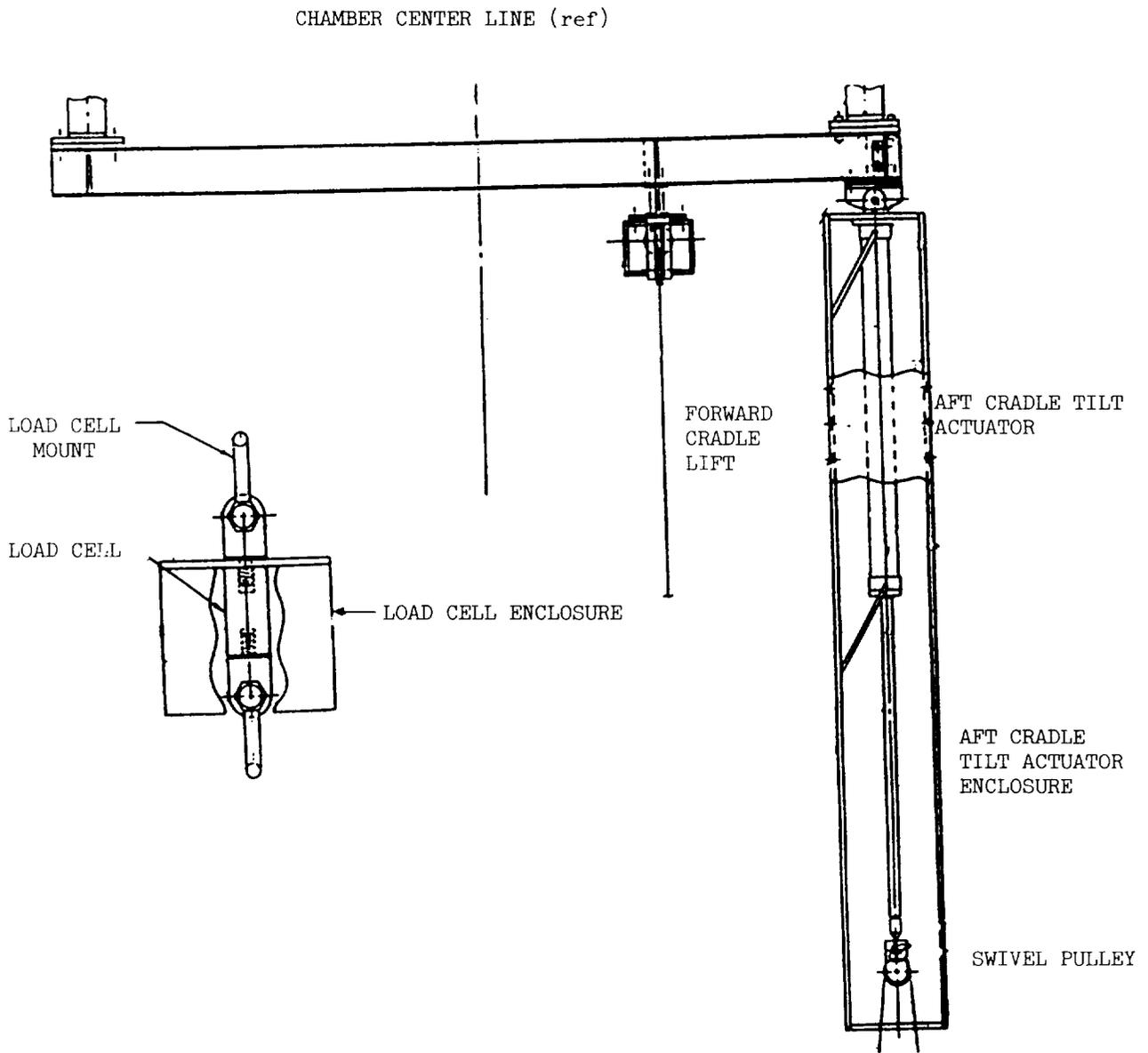


Figure 4. Aft Cradle Tilt Actuator

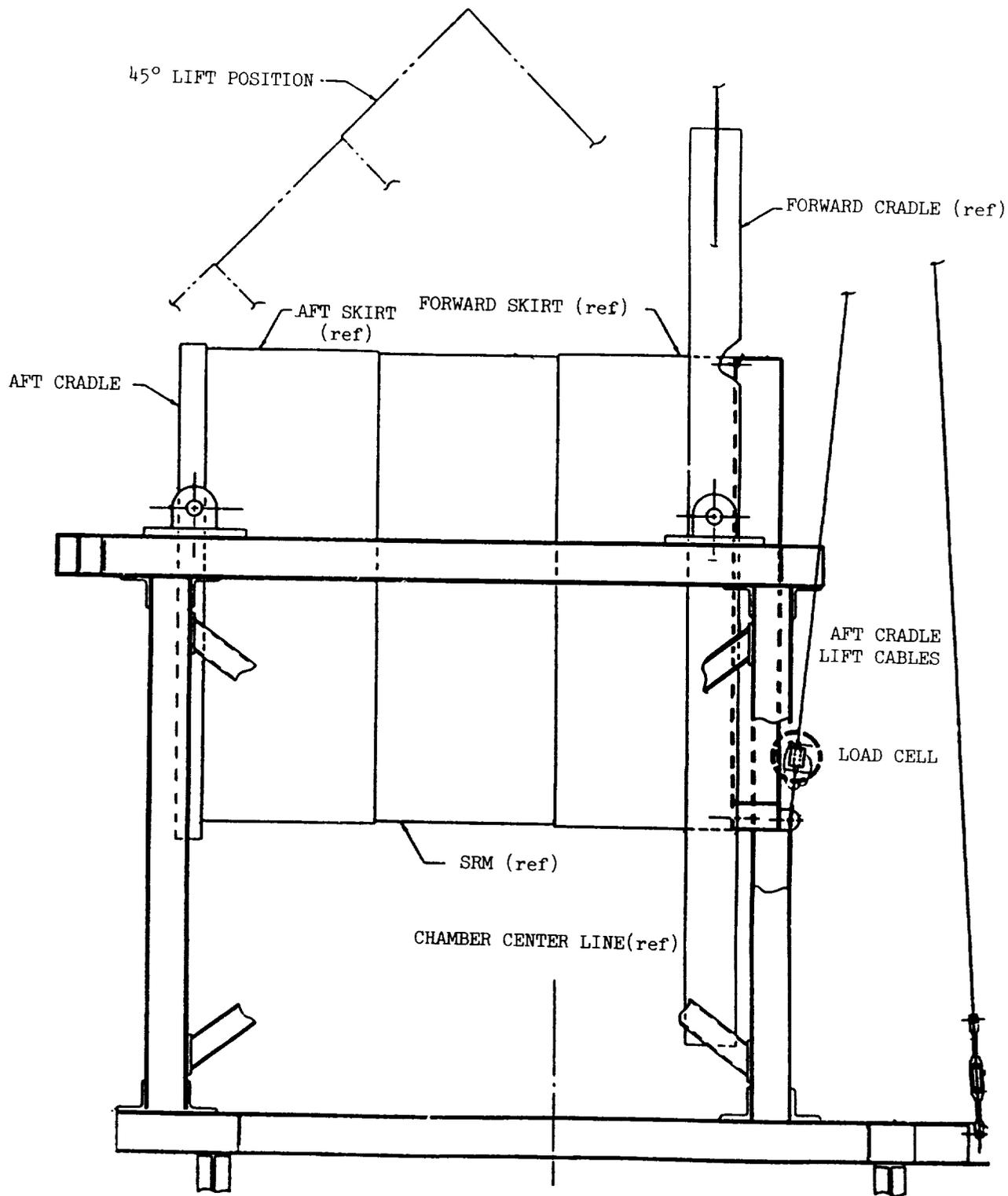


Figure 5. TOS in Chamber